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CRITICAL EVALUATION OF ATMOSPHERIC POLLUTANT PARAMETERIZATION FROM SATELLITE IMAGERY

N. T. O'Neill*, A. Royer, L. Hubert, **CARTEL**, Université de Sherbrooke, Sherbrooke, Qué.,

J. R. Miller, J. Freemantle, **CRESS**, York University, Downsview, Ont.,

G. Austin, A. Davis, McGill University, Montréal, Qué.

In spite of overwhelming advantages in spatial samping density and spatial coverage the remote sensing of atmospheric constituents represents a monitoring methodology which is often more qualitative than quantitative. The sensitivity of existing techniques for the inversion of satellite imagery data is not well understood in terms of discriminating constituent types and threshold levels of detection. The objective of the present study was to simulate the atmospherically scattered signal received by a satellite sensor and hence to evaluate the sensitivity of this signal to atmospheric aerosols in general and to atmospheric pollutants in particular. In the long term this type of research is geared towards the development of an operational satellite monitoring system within the context of the long range transport of atmospheric pollutants (LRTAP) programs.

The simulations were performed as a function of environmental, geometrical and operational parameter constraints. The environmental modelling included the effects of urban and rural type aerosols where the absolute and relative concentration of water soluble (sulphate) particles was allowed to vary and where particle growth and refractive index effects of relative humidity variations was incorporated. Combined aerosol modes which included fine particle (sulphate based) coarse particle (silicate based) and absorptive aerosols (carbon based) were incorporated as external (independent) aerosol mixtures. Some tests were performed in terms

of internal aerosol mixtures in order to evaluate the effect of the mixture assumption on the results of the sensitivity study.

The variability of the simulated signals indicate that information on the vertically integrated contribution of submicron scattering and absorbing aerosols can be usefully extracted. Inasmuch as the dominant optical variations occur in the lower troposphere this extracted information can be correlated with ground level concentrations. Furthermore, investigations into the dependence of the satellite signal on variations in optical mixing ratios with altitude indicated a degree of insensitivity which significantly simplifies the radiative transfer calculations and the inversion methodology.

The optical effects of ground level sulphates (predominantly in the form $(NH_4)_2SO_4$) are strongly influenced by the ambient relative humidity. This is less an effect of a change in refractive index than an increase in particle size according to the mechanisms of droplet growth. Such induced variations in optical activity result in a ground level sulphate scattering power which may vary by a factor of 4 or 5 across the naturally occurring range of relative humidity. The implications of this variation in terms of satellite remote sensing is that one must be aware of the average atmospheric water vapour parameters in order to obtain quantitative inversions for ground level sulphate concentration. As well the relative weakness of the signal in dry atmospheric conditions represents a degradation factor in terms of sulphate sensitivity.

The specificity of coarse (spectral) band remote sensing for sulphate detection is more a function of the dominance of fine particle (water soluble) aerosols in terms of optical effects

and in turn the predominance of the sulphate fraction in the water soluble component. At ground level the optical contribution due to sulphates is typically the largest particularily in conditions of high relative humidity and total extinction. Accordingly, even in the absence of information relating to the contribution of other components one can extract an estimate of wet sulphate number density to within a factor of 2 or 3. The extraction of dry sulphate number density can then be performed given relative humidity information.

An improvement of this figure can only be obtained by (1) effectively calibrating the satellite data with ground based concentration measurements or (2) by employing multispectral and temporal data to extract information on other contributions to the satellite signal. The atmospherically averaged aerosol size distribution, in addition to the integrated aerosol content, can be extracted if three or more absorption free wavelengths in the spectral region from 0.4 to 2.5 microns are available. Inversions for water vapour and NO_2 content can be performed if measurements are made at two or more wavelengths straddling absorption peaks in the near IR and near UV respectively.

The operational parameter constraints were keyed to the specifications of selected remote sensing satellites which are eithor operational or will be by at least 1995. These included the NOAA and GOES meteorological satellite series, the Landsat and SPOT resource monitoring satellites, the oceanographic satellite SEAWIFS, and the high spectral resolution imaging spectrometers (MODIS and HIRIS) which will be incorporated into the space station package. The meteorological satellites offer a relatively high rate of image repetition over the same area but are constrained to one or two coarse spectral bands and a large spatial resolution. The current SPOT and Landsat satellites acquire high spatial resolution images (order of tens of

meters) at comparatively high spectral resolution but with a repetition cycle (order of weeks) which is not suited to the time scale of regional transport studies. The next generation of resource satellites SPOT-4 and SEAWIFS offer both a spectral resolution and a repetition rate (2 days) which more closely approximates the requirements for passive atmospheric remote sensing. Within the near future the HIRIS and MODIS sensors possibly coupled with vertical structure data from the laser sounder (LASA) represent the realisation of a sensor package for which one of the major design constraints was the remote sensing of atmospheric constituents.

A comparison of radiative transfer models indicated that the analytical 5S model developed by D. Tanré and co-workers represented the most optimal comprimise of speed and accuracy in terms of applying a pixel by pixel inversion algorithm to large satellite images. Comparison with a multiple scattering, multiple layer model demonstrated however that, for certain geometrical conditions, inversion errors of the order of .1 in aerosol optical depth could result. This necessitated certain model refinements which were related to the manner in which aerosol and molecular scattering were coupled.

The study also showed that special algorithms were required to overcome difficulties associated with inversion singularities over surfaces whose reflectances were such that the effects of surface transmission and atmospheric scattering were counterbalanced. The extraction of atmospherically scattered signals from the total signal received by the satellite sensor implies some apriori knowledge of the ground surface reflectance in the satellite image. To a certain degree this requirement can be circumvented by restricting measurements to water bodies and by utilizing bands in the near IR spectral region. However to fully exploit the potential of the satellite data requires a calibration program involving the establishment of reflectance

calibration sites and the temporal analysis of repetitive satellite images.

The simulation analysis was sufficiently promising to warrant a program of simultaneous ground based, airborne and satellite measurements as a subsequent phase to the present work. This program should include as well the acquisition and analysis of high spectral resolution airborne data to address the specificity problem.